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A SIMULATION-OPTIMIZATION MODEL FOR AUTOMATED PARCEL LOCKERS NETWORK DESIGN IN URBAN SCENARIOS IN PAMPLONA (SPAIN), ZAKOPANE, AND KRAKOW (POLAND)

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ABSTRACT

The constant rise of e-commerce coupled with extremely fast deliveries is a significant contributor to saturate city centers' mobility. To address this issue, the development of a convenient Automated Parcel Lockers (APLs) network improves last-mile distribution by reducing the number of transportation vehicles, the distances driven, and the delivery stops. This article aims to define and compare APL networks in the cities of Pamplona (Spain), Zakopane and Krakow (Poland). Thereby, a bi-criteria weighted-sum simulation optimization model is developed for a representative year for the aforementioned cities. The simulation forecasts the e-commerce demands whereas the optimal APL network is obtained with a bi-criteria maximum APL revenues and minimum network costs. Meaningful results are obtained from the multi-criteria hybrid model outcomes as well as from the cities comparison. These outcomes suggest efficient APLs networks considering cultural and demographic factors for a massive use of APLs in high-demand periods.

1 INTRODUCTION

The last decade has been characterized by a huge increase in online consumption of physical goods and services, thus giving rise to the need to develop a technology and distribution system that is up to the demand. Thereby, the e-commerce has been developed. Urban Logistics is becoming increasingly important due to the global rise of e-commerce with home deliveries of small but frequent orders from consumers. Alternative delivery methods have been on the radar of researchers and delivery companies for years (Sawik et al. 2017a). The objective of any distribution and delivery company is the speed and effectiveness of parcel delivery, always seeking to improve and optimise its services (Sawik et al. 2017b), considering also the environmental impact of this process (Abdullahi et al. 2021). Therefore, in the period 2013-22, the APLs (Automated Parcel Lockers) market has been evolving and growing. Parcel locker, known as smart locker is a service point involved in self-collection service. It helps providers or delivery companies minimize failed deliveries, enabling couriers to deliver the parcels in less time and avoiding unnecessary waits. Moreover, lockers give the option of depositing all the parcels of the inhabitants of the same area at the same collection point, which allows for a reduction in the number of trips, thus increasing the efficiency of the process. In addition, consumers can significantly reduce opportunity costs by choosing time and place for goods pickup, namely any time of the day, per their convenience. So, for logistic companies, investment in parcel lockers can reduce costs in the logistic chain, and increase delivery efficiency, generating new market opportunities. A smart locker is an element that provides both consumers and delivery companies with a 24-hour pick-up and delivery service. Packages purchased online are deposited at a nearby APL, a locker facility with a digitised interface. Notification messages are then sent to consumers, informing them about the collection location and password needed to access the designated locker. Most of these collection points are located strategically within walking distances from residential areas, which makes them easily accessible and encourages their use. They are usually located in close proximity to business centres, financial areas, workplaces, petrol stations, shopping or cultural centres. Any place where there is a high concentration of people with high internet shopping frequency profiles is attractive for the installation of smart lockers.

Finally, this article is the natural sequel of the papers written by Serrano-Hernandez et al. (2021), and Rabe et al. (2020), which analysed the APLs policies in different scenarios inside European cities. The seminal paper of our work is Serrano-Hernandez et al. (2021), which developed a comparison between the cities of Pamplona (Spain) and Dortmund (Germany) concerning APLs decision making in the context of urban distribution. The main differences from the previous works rely on three aspects. Firstly, the simulation-optimization framework with the implementation of a bi-objective optimization model. Secondly, the application of the model to additional cities, which implies the consideration of other culture-related parameters to tune the models. Finally, a richer analysis of the results, highlighting differences in the cities leading to more meaningful managerial implications. This will be described in the forthcoming sections. Thus, next section reviews relevant literature about APLs, Section 3 describes the proposed methodology whereas Section 4 defines the computational experiments and presents the main results. Finally, Section 5 highlights the main implications and concludes the paper.

2 LITERATURE REVIEW

This section presents a description of the work related to APLs which helps the reader to understand our model. The use of APLs is an important step forward in the development of the last mile distribution in urban delivery of goods and merchandises. Nowadays, the use of APLs has been revealed as a very convenient experience for many customers (Chen et al. 2020; Vakulenko et al. 2018), apart from its suitability for parcel urban logistics (Yuen et al. 2018). Its success is mainly due to the failed delivery problems observed in the urban distribution of goods (Rai et al. 2021). Furthermore, Tsai and Tiwasing (2021) has recently pointed out the increasing popularity of APLs among customers, when they have to choose the delivery mode and pick-up system for their purchases. Therefore, an optimum design of the urban network of APLs is needed considering their potential population of users, their associated costs and their efficiency. Thus, Deutsch and Golany (2018) developed an initial paper to optimize the APLs network, which has been complemented by the study of Schwerdfeger and Boysen (2020), who designed some accurate models to build an APLs distribution structure. Another important aspect of the APLs appropriateness for last mile urban distribution is their contribution to the improvement of pollution in urban centers (Gatta et al. 2019; Brown and Guiffrida 2014), due to the fact of the substitution effect in relation to delivery vans. Likewise, the COVID-19 outbreak and its evolution during the years 2020-21 has impulsed the use of e-commerce and, as a consequence, the number of APLs in the urban areas have mushroomed (Figliozzi and Unnikrishnan 2021). Thus, this boom of e-commerce has involved the need for optimizing the APLs network using different methodologies of simulation-optimization techniques. For instance, Lin et al. (2020) designed some interesting optimization models to implement the APLs network structure in Singapore. Similarly, Alves et al. (2019) built an agent-based simulation model to evaluate the current APLs network in the Brazilian city of Belo Horizonte.

3 METHODS

As we have previously noted, this paper extends the models presented in Serrano-Hernandez et al. (2021). Thus, an agent-based model (ABM) is implemented in the current paper to forecast parcel demand placed on APLs based on socio-economic factors for a three years planning horizon. For a more detailed study of our methodology, we recommend the paper of Macal (2016) for a complete review on ABM, the work of Oliveira et al. (2016) for a review of simulation in logistics and transportation, and Serrano-Hernandez et al. (2018) for a particular example of ABM in transportation. Additionally, a bi-criteria weighted-sum simulation-optimization facility location model is rooted within the simulation framework featuring the optimal number and location of APLs. Note that the simulation environment supplies the input data for the facility location model, whereas this one provides the initial simulation data.

3.1 The Simulation Framework

ABM is implemented in Anylogic software (AnyLogic 2022) in order to estimate future APL parcel demands as an input data for the bi-objective facility location model. The simulation optimization approach is summarized in the Figure 1 and contains the following key variables:

- Population. The general population of the city on a district basis. This variable grows as a consequence of the population growth rate.
- eShoppers. The portion of population that usually orders online. Similarly, this variable evolves because of the population growth and the eShoppers growth rates.
- APL users. The portion of eShoopers that normally uses an APL. Likewise, APL users will vary when population and eShoppers do and as a consequence of its own growth rate.
- APL parcel demands. This is the number of orders place by an APL user. The number of APL users will increase as a consequence of the evolution of previous variables and because of the actual presence of APL nearby. This implies that having an APL close to a customer residence will encourage its use. This is also extended to the number of APLs.
- Growths. This variable represents the expected growths in the aforementioned variables.
- Number of APL. The current number of APLs available in the city.
- Location of APL. The current locations, on a district basis, of the APLs in the city.

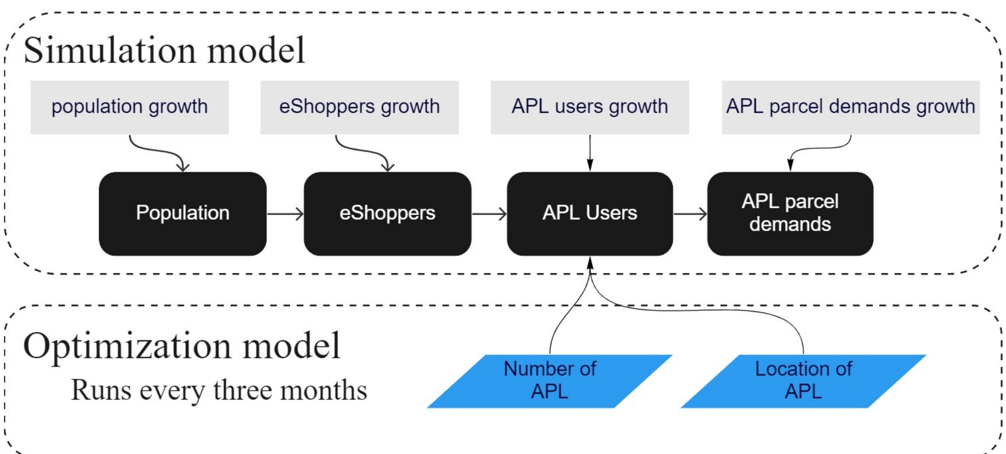

Figure 1: Simulation Optimization flowchart.

The dynamics of the simulation starts with initial population, eShoppers, APL users, and parcel demands that feeds the first facility location model. This will create the initial APL network in the city. Later, the different variables begin to evolve according to the expected growths (see the Figure 1. After a given period of time, the facility location model is again solved with the current data. This situation again provides a new APL network that affects the forthcoming APL users. For the computational experiments, we considered running the optimization model every three months due to the fact this is a reasonable time period in which an APL can be set up, removed or moved to another district. This procedure is further described in the the following subsection. Anyway, the reader is suggested to review the methodological section in Serrano-Hernandez et al. (2021) for more details.

3.2 The Bi-Criteria Facility Location Model

A bi-criteria facility location problem (BCFLP) is integrated within the simulation framework and solved using IBM®ILOG CPLEX 12.6.2 (IBM ILOG CPLEX Optimization Studio 22.1.0) API for the Java-based Anylogic Environment. For comparison of optimization model, computational experiments were performed using the AMPL programming language and the Gurobi 9.0.2 solver on a MacBookAir laptop with Dual-Core Intel Core i7 processor running at 1.7GHz and with 8GB RAM. The size of the mixed integer programs for the example problems were relatively small. This bi-criteria weighted-sum optimization model is defined over set nodes $i \in \mathscr{I}$ and $j \in \mathscr{J}$ representing the districts and customers, respectively. This BCFLP seeks the optimal location of APLs and assignment of customers to districts hosting APLs in such a way total costs are minimized and revenues are maximized subject to a number of constraints. In this respect, Table 1 shows the model variables, Table 2 shows the model parameters and Table 3 presents objective function criteria.

Table 1: Model variables.

Variable	Description
x_{ij}	1 if customer $j \in \mathscr{J}$ is assigned to APL located at district $i \in \mathscr{I}$
y_i	Number of APLs located at district $i \in \mathscr{I}$
yIn_i	Number of new APLs set up at district $i \in \mathscr{I}$
$yOut_i$	Number of APLs retired from district $i \in \mathscr{I}$
$h1_i$	Auxiliary variable
$h2_i$	Auxiliary variable

Table 2: Model parameters.

Parameter	Description
λ	weights in the objective function (changed by the decision maker)
c_{ij}	Cost of assigning customer $j \in \mathscr{J}$ to an APL located at $i \in \mathscr{I}$
d_j	Demand of customer $j \in \mathscr{J}$
sc_i	Cost of setting up an APL at district $i \in \mathscr{I}$
dc_i	Cost of decommissioning an APL at district $i \in \mathscr{I}$
uc_i	Cost of keeping working an APL at district $i \in \mathscr{I}$
r_i	Revenue from located APL at district $i \in \mathscr{I}$
m	Minimum percentage of an APL capacity utilization
a_i	APL capacity at district $i \in \mathscr{I}$
$y_{i(t-1)}$	Number of previously existing APL at district $i \in \mathscr{I}$

Table 3: Costs vs. Revenue parts of criteria included in objective function.

Weight	Costs vs. Revenue	Min vs. Max	Parts of Criteria	Description
λ	Costs	Minimization	$\sum_{i\in\mathscr{I}, j\in\mathscr{J}} c_{ij}d_jx_{ij}$	Costs of assignment of all customers at all districts
			$\sum_{i\in\mathscr{I}} sc_i(yIn_i)$	Costs of setting up all new APLs at all districts
			$\sum_{i\in\mathscr{I}} dc_i(yOut_i)$	Costs of all decommissioning APLs at all districts
			$\sum_{i\in\mathscr{I}} uc_i(y_i)$	Costs of keeping all working APLs at all districts
$1-\lambda$	Revenue	Maximization	$\sum_{i\in\mathscr{I}} r_i(y_i)$	Revenue per all located APL at all districts

Afterwards, the FLP is defined as follows:

$$Min \quad \lambda Costs \quad versus \quad Max \quad (1-\lambda)Revenue, \quad \lambda \in (0,1) \tag{1}$$

Objective function (1) is equivalent to following mathematical formulation:

$$Min \quad \lambda(\sum_{\substack{i\in\mathscr{I}\\ j\in\mathscr{J}}} c_{ij}d_jx_{ij} + \sum_{i\in\mathscr{I}} sc_i(yIn_i) + \sum_{i\in\mathscr{I}} dc_i(yOut_i) + \sum_{i\in\mathscr{I}} uc_i(y_i)) - (1-\lambda)(\sum_{i\in\mathscr{I}} r_i(y_i)) \tag{2}$$

subject to

$$yIn_i = y_i - y_{i(t-1)} + h1_i, \forall i \in \mathscr{I} \tag{3}$$

$$yOut_i = y_{i(t-1)} - y_i + h2_i, \forall i \in \mathscr{I} \tag{4}$$

$$\sum_{i\in\mathscr{I}} x_{ij} = 1, \forall j \in \mathscr{J} \tag{5}$$

$$Mx_{ij} \geq y_i, \forall i \in \mathscr{I}, \forall j \in \mathscr{J} : i = j \tag{6}$$

$$\sum_{j\in\mathscr{J}} d_j \geq m \sum_{i\in\mathscr{I}} a_i y_i \tag{7}$$

$$\sum_{j\in\mathscr{J}} d_j x_{i,j} \leq a_i y_i, \forall i \in \mathscr{I} \tag{8}$$

$$x_{ij} \in \{0,1\}, \forall i \in \mathscr{I}, \forall j \in \mathscr{J} \tag{9}$$

$$y_i, yIn_i, yOut_i, h1_i, h2_i \in \mathbb{Z}^+, \forall i \in \mathscr{I} \tag{10}$$

The bi-criteria weighted-sum objective function (2) defines the minimization of total costs related with APLs location and use versus maximization of revenue per located APLs that comprise the items described in the following lines, beginning with the service costs of assigning costumers to districts where an APL is available. These service costs depend on the distance and demand. The second term represents the costs of setting up the APL and the third one the costs of decommissioning an existing APL. Fourthly, the cost of maintaining an APL from one time period decision to the following is included (see Table 3 for a summary of BOFLP criteria). Note that for our computations in this paper we set $\lambda = 0.5$ for simplicity reasons. Constraints (3) and (4) define the number of new APL to set up and the number of APL to remove, respectively. The auxiliary variables $h1$ and $h2$ are used for each $i \in \mathscr{I}$ in order to fulfill the equations. Constraints (5) force each customer $j \in \mathscr{J}$ to be assigned to a district $i \in \mathscr{I}$ where an APL is available. Similarly, constraints (6) force each customer $j \in \mathscr{J}$ to be assigned to its own district if there is an APL located. M stands for a sufficiently large number - highest estimation. Besides, equation (7) ensures a minimum APL utilization for a given demand, whereas (8) guarantees demand assigned to any APL will be lower or equal to the installed capacity. Finally, expressions (9) and (10) define the variable ranges.

4 COMPUTATIONAL EXPERIMENTS

A standard scenario is selected to test the hybrid simulation-optimization model in three different cities from two European countries. Firstly, Zakopane, a small-size city at Southern Poland. Secondly, Pamplona, a medium-size city in Northern Spain. Finally, Krakow, one of the largest cities in Poland. Therefore, culture-related parameters have been applied to tune the model. Districts and populations for the aforementioned cities are shown in Table 4. Likewise, time series analysis are used to estimate population growths in Poland and Spain. Additionally, ad-hoc surveys, as well as external sources are used for estimating current values for e-Shoppers, APL users and demand distributions (IAB Spain (2021); Coppola (2021); Ward (2021); BIP Zakopane (2022); BIP Krakow (2022)).

A summary of the initial values for the simulation is available in Table 5 whereas the optimization parameters are shown in Table 6. Table 7 presents number of automated parcel lockers (APL) located in districts of Pamplona, Zakopane, and Krakow before and after computations. Finally, no public data are available regarding e-commerce in Pamplona, Zakopane and Krakow, and initial data are gathered from direct observation and using different national and international secondary resources. According to these

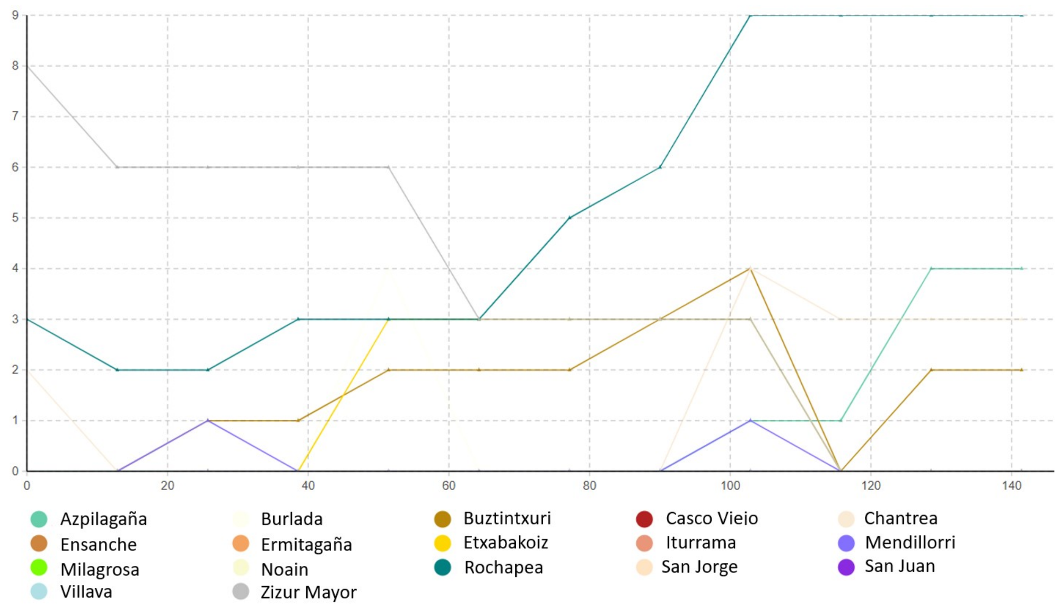

Figure 2: APL evolution in Pamplona districts.

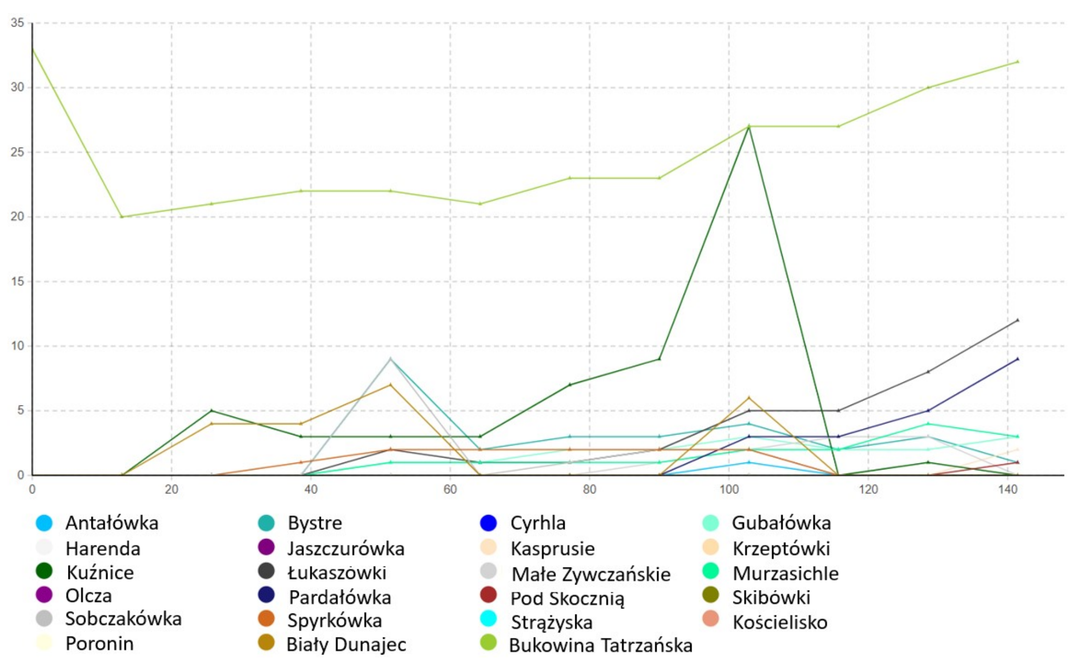

Figure 3: APL evolution in Zakopane districts.

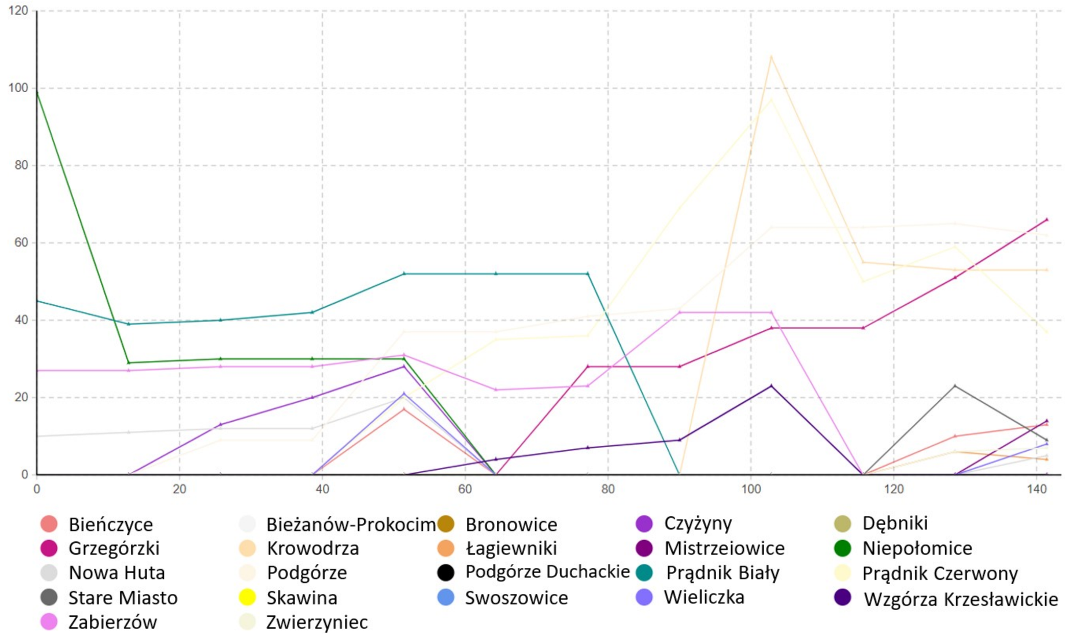

Figure 4: APL evolution in Krakow districts.

primary data, the mean size of APLs already active is 72 cubicles, which can be used for the delivery of a new parcel from Monday to Friday, adding up to a total capacity of a_i = 360 parcels per week. In addition, minimum capacity utilization can be fixed to m = 30 % after analysis of the gathered real data.

The initial values of simulation-related parameters for the bi-objective optimization-simulation model presented in Table 5 have been selected on the basis of information from the eShoppers surveys, the analysis of demographic data of considered cities, as well as external sources. These sources together with the demand distributions, and time series analysis have been used for estimating current values for e-Shoppers and APL users, and to estimate average e-purchases per year, yearly eShoppers growth rate, yearly APL users growth rate, yearly parcel demand growth rate, and in general population growths in Spain and Poland (IAB Spain (2021); Coppola (2021); Ward (2021); BIP Zakopane (2022); BIP Krakow (2022)).

5 RESULTS AND CONCLUSIONS

The results were based on real data from three different cities from two European countries. Firstly, Zakopane, a small city in southern Poland. Secondly, Pamplona, a medium-sized city in northern Spain. And finally, Krakow, one of the largest cities in Poland. Therefore, culture-related parameters have been applied to tune the model. A standard scenario was selected to test the hybrid simulation and optimization model. Thus, this work proposed the use of a bi-criteria weighted-sum simulation-optimization model by combining simulation and optimization to deal with automated parcel locker (APL) networks in the cities of Pamplona (Spain), Zakopane and Krakow (Poland). On the one hand, the bi-criteria weighted-sum simulation-optimization model is based on agent-based modeling and evaluates the evolution of the population, eShoppers, APL users, and parcel demand. On the other hand, the optimization model decides the number and location of APLs through a bi-objective facility location problem (BOFLP). Thus, the system establishes the link between the outputs of one model and the other one. In this context, standard scenarios were tested for a range of growth levels of APL users and the sensitivity of eShoppers to become APL users once there is an APL nearby. A list of conclusions can be drawn after the analysis of the results.

Conclusion 1. Costs, revenue and suggested number of lockers: Firstly, our results anticipate an increase in the magnitudes of population, eShoppers, APL users, parcel demands, and number of APLs for the coming years in the cities of Pamplona, Zakopane and Krakow, considering a realistic standard scenario

Table 4: District populations: Pamplona, Zakopane, and Krakow.

Pamplona (Spain)	
District	Population
Total	231,102
Azpilagaña	7,374
Burlada	18,934
Buztintxuri	8,771
Casco viejo	11,187
Chantrea	19,450
Ensanche	25,994
Ermitagaña	16,798
Echavacoiz	5,255
Iturrama	22,976
Mendillorri	10,966
Milagrosa	17,552
Noáin	8,224
Rochapea	25,739
San Jorge	11,994
San Juan	19,888
Villava	10,150
Zizur Mayor	14,891

Zakopane (Poland)	
District	Population
Total	67,647
Antałówka	133
Bystre	564
Cyrhla	870
Gubałówka	132
Harenda	2,120
Jaszczurówka	1,048
Kasprusie	2,640
Krzeptówki	2,560
Kuźnice	162
Łukaszówki	2,345
Małe Żywczańskie	1,324
Murzasichle	1,415
Olcza	3,102
Pardałówka	1,374
Pod Skocznią	538
Skibówki	2,720
Sobczakówka	2,380
Spyrkówka	1,062
Strążyska	1,334
Kościelisko	8,893
Poronin	11,743
Biały Dunajec	7,125
Bukowina Tatrzańska	13,478

Krakow (Poland)	
District	Population
Total	771,834
Bieńczyce	39,007
Bieżanów-Prokocim	62,797
Bronowice	24,218
Czyżyny	32,407
Dębniki	64,156
Grzegórzki	29,740
Krowodrza	29,940
Łagiewniki-Borek Fałęcki	15,282
Mistrzejowice	50,950
Nowa Huta	48,194
Niepołomice	12,507
Podgórze	38725
Podgórze Duchackie	54,140
Prądnik Biały	71,788
Prądnik Czerwony	46,104
Stare Miasto (Old Town)	29,143
Skawina	24,325
Swoszowice	29,087
Wieliczka	23,395
Wzgórza Krzesławickie	20,057
Zabierzów	5,542
Zwierzyniec	20,330

Table 5: Comparison of Pamplona, Zakopane and Krakow simulation-related parameters: population per city, current eShoppers, current APL users, yearly APL users growth rate, yearly parcel demand growth rate.

Parameter	Pamplona (Spain)	Zakopane (Poland)	Krakow (Poland)
Population	231,102	67,647	771,834
eShoppers	0.63population	0.83population	0.73population
APLusers	0.022eShoppers	0.055eShoppers	0.044eShoppers
Average e-purchases per year	42	126	84
Yearly eShoppers growth rate	0.1	0.1	0.1
Yearly APL users growth rate	0.10	0.15	0.15
Yearly parcel demand growth rate	0.2	0.2	0.2

Table 6: Parameters for the bi-objective facility location model.

Parameter	Poland	Spain
r_i	11,625	19,960
sc_{ij}	2,750	3,000
c_{ij}	Distance based	
uc_i	175	300
dc_i	90	150
m	0.3	
a_i	360	
λ	0.5	

Table 7: Number of APLs located in districts before and after computations: Pamplona, Zakopane, and Krakow.

Pamplona District	Number of APLs before	after
Total	23	24
Azpilagaña	1	2
Burlada	1	1
Buztintxuri	1	2
Casco viejo	0	1
Chantrea	0	2
Ensanche	5	3
Ermitagaña	1	1
Echavacoiz	0	1
Iturrama	1	1
Mendillorri	0	1
Milagrosa	0	1
Noáin	5	2
Rochapea	2	2
San Jorge	1	1
San Juan	1	1
Villava	1	1
Zizur Mayor	3	1

Zakopane District	Number of APLs before	after
Total	41	54
Antałówka	0	1
Bystre	1	2
Cyrhla	0	1
Gubałówka	0	1
Harenda	1	1
Jaszczurówka	0	1
Kasprusie	1	2
Krzeptówki	2	1
Kuźnice	0	1
Łukaszówki	2	2
Małe Żywczańskie	0	1
Murzasichle	1	1
Olcza	2	2
Pardałówka	1	2
Pod Skocznią	2	1
Skibówki	2	2
Sobczakówka	1	2
Spyrkówka	1	2
Strążyska	0	1
Kościelisko	5	5
Poronin	5	5
Biały Dunajec	4	5
Bukowina Tarzańska	10	12

Krakow District	Number of APLs before	after
Total	58	74
Bieńczyce	2	2
Bieżanów-Prokocim	2	2
Bronowice	1	1
Czyżyny	1	3
Dębniki	1	1
Grzegórzki	2	4
Krowodrza	4	4
Łagiewniki-Borek Fałęcki	3	4
Mistrzejowice	3	4
Niepołomice	2	2
Nowa Huta	4	5
Podgórze	3	4
Podgórze Duchackie	4	5
Prądnik Biały	4	5
Prądnik Czerwony	4	5
Stare Miasto	3	4
Skawina	3	4
Swoszowice	2	2
Wieliczka	3	5
Wzgórza Krzesławickie	3	3
Zabierzów	2	2
Zwierzyniec	2	2

for it. As it is shown in Table 8, Zakopane population would raise up to the 69,062–72,174 interval, whereas eShoppers would do up to the 57,342–59,877 range. Similarly, the population of Pamplona would raise up to the 256,233–267,655 interval, whereas eShoppers would do up to the 161,598–185,949 range. Furthermore, the population of Krakow would also raise up to the 773,020–806,824 interval, whereas eShoppers would do up to the 565,658–611,116 range. Correspondingly, APL users and parcel demands will continue increasing according to our experiments for Zakopane, Pamplona and Krakow. Likewise, depending on the considered scenario of APL growth and sensitivity. As a result of those increases in all compared cities costs and revenue related with population and eShoppers determines the growth in number of APLs. Note that the decisions about the number and location of APLs are obtained from a bi-criteria weighted-sum optimization model (Equations(1)–(10)).

Conclusion 2. Comparison between Zakopane, Pamplona, and Krakow: There are some similarities and differences between results of optimization and simulations for APLs in three considered cities. Case of Zakopane and Krakow versus Pamplona shows (see Table 5) different dynamic of growth in use of APLs by eShoppers, wherefore increase of this use is slower in Pamplona, when comparing with Zakopane and Krakow. When comparing size of the cities and locations of APLs (see Figures 2, 3 and 4) Zakopane is the city with the highest dynamic of APLs usage, second is Krakow, and third is Pamplona. Considering the comparison between real locations of APLs in each district of considered three cities vs. obtained locations of APLs after solving the bi-criteria weighted-sum simulation-optimization model (see Table 7) it can be observed, that model is trying to balance number of APLs in each district. Pamplona has 4% increase in numbers of APLs, Zakopane has 32% increase and Krakow has 28% increase. When we are considering financial relations (see Table 9) between size and growth of population, eShoppers, APLs users and parcel demand versus APLs revenue, costs and number of automated parcel lockers, it can be concluded, that most profitable investment in APL infrastructure is located in Zakopane, second one location is Krakow, and the least profitable in Pamplona. These relations of highest to lowest APLs revenue in each city measured by €per permanent resident, €per eShopper, €per APL user, and €per parcel demand is also true for APLs costs. In sense, that most profitable cities, have highest APLs costs, as well. Relation between number of permanent residents, eShopper, APL users, parcel demand to number of automated parcel lockers in

Table 8: Results of a bi-criteria weighted-sum optimization-simulation model for three years for Pamplona, Zakopane, and Krakow.

Change in numbers	Value	Pamplona	Zakopane	Krakow
Population	Minimum	256,233	69,062	773,020
	Average	257,861	69,595	783,964
	Maximum	267,665	72,174	806,824
eShoppers	Minimum	161,598	57,342	565,658
	Average	174,270	58,711	590,074
	Maximum	185,949	59,877	611,116
APLs users	Minimum	35,513	31,645	247,913
	Average	42,111	43,478	310,012
	Maximum	49,139	57,703	388,154
Parcels demand	Minimum	25,554	68,695	101,229
	Average	55,953	175,687	832,994
	Maximum	133,897	454,743	2,036,180
APLs Revenue	Minimum	159,704	232,500	1,232,000
	Average	284,839	511,424	2,396,856
	Maximum	499,012	976,500	4,325,000
APLs opening Costs	Minimum	0	2,750	5,500
	Average	11,250	35,298	172,762
	Maximum	39,000	107,250	497,750
APLs service Costs	Minimum	83,184	58,477	422,758
	Average	159,155	146,935	806,769
	Maximum	284,657	292,549	1,441,000
APLs upkeep Costs	Minimum	2,400	3,500	18,550
	Average	4,281	7,699	35,853
	Maximum	7,500	14,700	65,100
APLs closing Costs	Minimum	0	0	0
	Average	336	688	3,545
	Maximum	1,962	3,780	15,570
Number of APLs	Minimum	8	20	50
	Average	14	44	205
	Maximum	25	84	372

Table 9: Financial relations for APLs Costs and Revenue vs size and growth of population, eShoppers, APLs users, and parcel demand in Pamplona, Zakopane, Krakow.

Revenue/Costs	Relation between:	Pamplona	Zakopane	Krakow
APL Revenue	€/ permanent resident	1.10	7.35	3.06
	€/ eShopper	1.63	8.71	4.06
	€/ APL user	6.76	11.76	7.73
	€/ parcel demand	5.09	2.91	2.88
APL Costs	€/ permanent resident	0.68	2.74	1.30
	€/ eShopper	1.00	3.25	1.73
	€/ APL user	4.16	4.38	3.29
	€/ parcel demand	3.13	1.08	1.22

Table 10: Relation between number of permanent residents, eShopper, APL users, parcel demand to number of automated parcel lockers in Pamplona, Zakopane, and Krakow.

Relation between:	Pamplona	Zakopane	Krakow
number of permanent residents / number of APLs	18,419	1,582	3,824
eShopper / number of APLs	12,448	1,334	2,878
APL user / number of APLs	3,008	988	1,512
parcel demand / number of APLs	3,997	3,993	4,063

Table 11: Comparisons for APLs revenue and costs divided by the number of APLs in Pamplona, Zakopane, and Krakow.

Relation between:	Pamplona	Zakopane	Krakow
Revenue / number of APLs	20,346	11,623	11,692
Costs / number of APLs	12,502	4,332	4,970

Pamplona, Zakopane, and Krakow has been compared in Table 10. Two final comparisons for APLs revenue and costs divided by the number of APLs in each city presented in Table 11. These numbers shown how profitable is one APL, and how expensive in one APL in each city.

Conclusion 3. Enhancement of simulation-optimization methodology: Finally, this paper encourages the use of the hybrid methodology of simulation and optimization to deal with complex real world problems. In effect, complex systems require a combination of methodologies that are able to conveniently cope with a problem.

Based on analysis of obtained computational results of selected standard scenario with culture-related parameters applied to tune the model and to effectively test the hybrid simulation-optimization approach with use of bi-criteria weighted-sum model for three different cities from two European countries: Pamplona, a medium-size city in Northern Spain, Zakopane, a small-size city at Southern Poland, and Krakow, one of the largest cities in Poland. Moreover, a set of presented analysis have enabled comparison of costs and revenue between all considered cities. Thus, the obtained results shows symptomatic aspects of automated parcel lockers market in the considered cities from Spain and Poland.

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